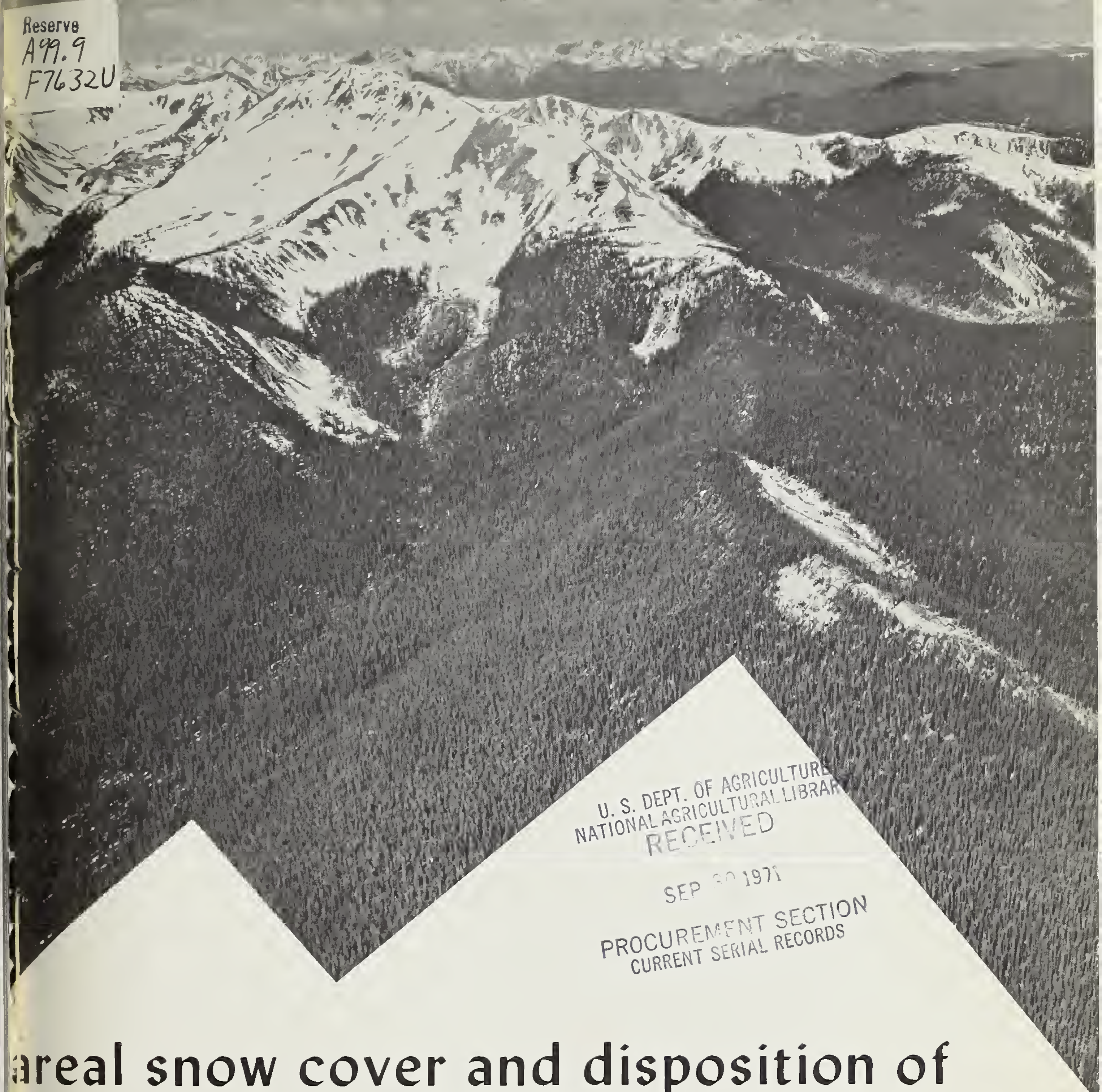

areal snow cover and disposition of snowmelt runoff in central colorado

By Charles F. Leaf

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Abstract

Areal snow-cover depletion and resultant snowmelt and water yield were studied on three small watersheds in the Fraser Experimental Forest.

High water yield efficiencies were observed on two watersheds which had: (1) almost complete snow cover when seasonal snowmelt rates on all major aspects were maximum; (2) a delayed and short snow-cover depletion season; and (3) moderate recharge and evapotranspiration losses.

Water yield efficiency in one watershed with low-elevation south slopes was least. In 1969, streamflow from the drainage area on this basin below 9,850 feet was less than 30 percent of that generated from above this elevation. Fourteen years of comparative streamflow indicated that water yields from the low-elevation subdrainage can vary from near zero in poor runoff years to a maximum during good years of about 50 percent of the flow generated from the high-elevation subdrainage.

Key words: Aerial photography, runoff, snow surveys, stream gaging, hydrologic cycle.

ABOUT THE COVER:

Snow cover in Byers Creek Basin, Fraser Experimental Forest, June 1970.

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Areal Snow Cover and Disposition of Snowmelt Runoff in Central Colorado

by

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Areal Snow Cover and Disposition of Snowmelt Runoff in Central Colorado

Charles F. Leaf

Introduction

The processes which produce stream runoff from snowmelt are too varied and too complex to be completely defined at this time. Hence, relatively simple relationships have been derived which empirically relate the more important factors in the hydrologic cycle for practical usage. Included in these types of relationships are correlations of the areal extent of snow cover with snowpack volume and streamflow. Such relationships have important application in (1) operational streamflow forecasting, and (2) hydrologic analysis of snow zone watersheds.

Streamflow Forecasting

Depletion-runoff relationships were first used for operational streamflow forecasting more than 30 years ago by Gross (1937), Parshall (1941), and Potts (1944). These early forecasting procedures were based on index observations of snow cover by ground photographic methods. In the 1950's, depletion-runoff forecast curves were developed by several investigators from estimates of total snow coverage on drainage basins (Brown and Dunford 1956, Garstka et al. 1958, Miller 1953, Parsons and Castle 1959). Thoms (1961) discussed residual volume forecasting procedures and summarized observations of areal snow cover in the Columbia River Basin since 1951. More recently, a supplement to this work has been published, which extends the summary through the 1968 spring runoff season (Thoms 1969, Thoms and Wang 1969). Leaf (1969), who summarized integral estimates of snow cover in central Colorado, derived residual volume forecast curves for three small experimental watersheds, based on records from the 1964 through 1968 snowmelt runoff seasons.

Hydrologic Analysis

Several of the investigators cited above have pointed out that every watershed has a characteristic relationship between snowpack depletion and the disposition of snowmelt runoff which can be explained by (1) geologic and topographic variability, and (2) the amount and distribution of forest cover. In other words, the empirical relationships derived for a given watershed apply only to that watershed, and reflect the effects of terrain diversity as well as ground water storage, and evapotranspiration losses. In addition to physiographic variations between watersheds, these correlations are also influenced by (1) the initial volume of the snowpack each year, and (2) meteorological conditions during each snowmelt runoff season. The effects of many of these factors are discussed in detail by Miller (1953) and the Corps of Engineers (U.S. Army 1956).

Areal snow-cover depletion, if correlated with (1) ablation (or melt) of the snowpack water equivalent, and (2) resultant streamflow, can provide a better understanding of the hydrology of snow zone watersheds. This report discusses the areal extent of snow cover in relation to the water balance on three small watersheds.

Study Area

The three study watersheds (figs. 1-3) are part of the Fraser Experimental Forest near Fraser, Colorado. They are tributary to flow of the Upper Colorado River Basin. Lodgepole pine and spruce-fir are the important forest types.[2] Deep, gravelly

[2] *Lodgepole pine (Pinus contorta)*
Engelmann spruce (Picea engelmanii)
Subalpine fir (Abies lasiocarpa)

Figure 1.--Fool Creek experimental watershed. Timber was removed from Fool Creek in 1954-56 to determine the effects of harvest cutting on streamflow.

Figure 2.--Lexen (left) and Deadhorse (right) experimental watersheds, Fraser Experimental Forest.

Figure 3.--Fool Creek watershed before harvest cutting.

soils overlay Pre-Cambrian bedrock; glaciatian has influenced the topography. Mare detailed discussions of the geology, climate, and water yields are found in Garstka et al. (1958), Hoover (1967), Leaf (1966), Retzer (1962).

Fool Creek Watershed

Snowpack Depletion

On Fool Creek, one of several gaged watersheds in the Fraser Experimental Forest, we are currently studying how harvest cutting influences streamflow (Haaver 1969, Hoover and Leaf 1967, Martinelli 1964). Treatment of this 714-acre watershed began in 1954 and was completed in 1956. Elevation of the watershed ranges from 9,600 feet at the stream gage ta abaut 11,500 feet, and slapes average 26 percent. The main channel flows narth; generally east- and west-facing aspects comprise 70 percent of the watershed area. Thus, radiant energy incident on the watershed surface is fairly uniform during the snowmelt runoff seasan.

The watershed research program on Fool Creek began in 1940. Observations during the pretreatment period (1940-54) generally began in early April and continued at periodic intervals thraugh the snawmelt season. In 1952 greater coverage of the watershed was abtained thraugh installation of additianal snowcourses. This discussion is based on comparisons with the snowcourse data collected during the 1952 snowmelt runaff season.

Each of 32 snowcourses established in 1952 was a sample plot 1 chain wide by 12 chains long (fig. 4). Twelve sample points were measured at 1-chain intervals on each plat. In addition to the plot snowcourses, cancurrent measurements were made on a 3.5-mile-long "figure-eight" snawcourse.

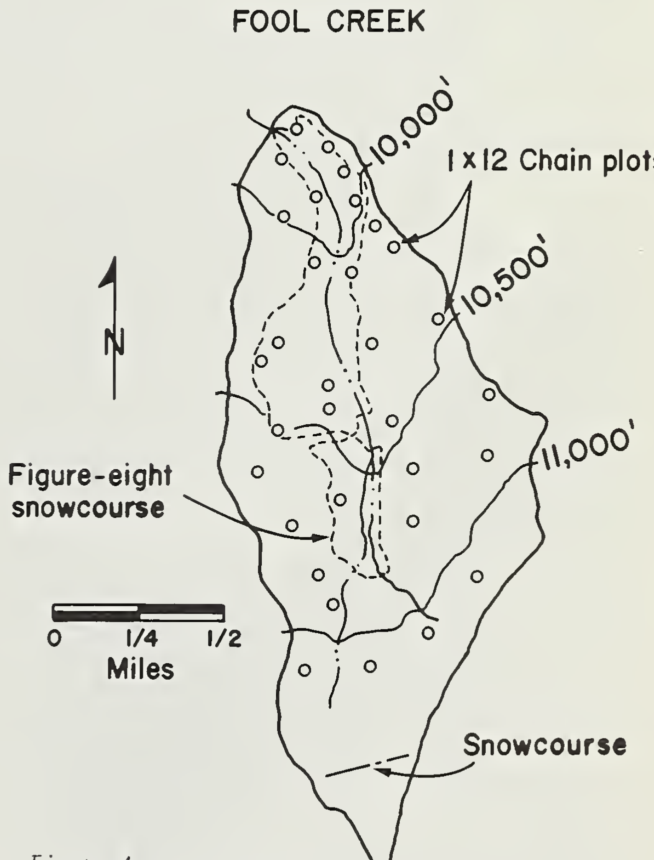


Figure 4.--Snowcourse locations on Fool Creek, 1952.

The data from 50 sampling points on this course were included along with a snowcourse near timberline. Sampling began April 10 and continued at weekly intervals through June 27, 1952 on the plots and figure-eight snowcourse. The upper course was surveyed on April 25. Individual measurements from all the sample points in the basin were used to estimate snow disappearance. Fool Creek was divided into six subunits, primarily on the basis of orientation since there were no abrupt changes in slope steepness and vegetation below timberline. Above 11,100 feet, forest cover is sparse, and the slope is gentle. This area was delimited as a separate subunit. Total watershed snow cover was determined by means of a weighted average based on the area and estimated snow cover in each subunit. These values were also weighted by means of the area-elevation curve to obtain an areal index of the input. Summaries of peak water equivalent and precipitation during snowmelt are shown for each elevation zone on the two major aspects of Fool Creek in table 1.

Runoff

Runoff from Fool Creek is gaged by a San Dimas flume (Garstka et al. 1958). The streamflow hydrograph for 1952 is plotted in figure 5. Because there is considerable storage delay of snowmelt inputs to the watershed, the hydrograph was separated into generated components. Generated runoff is defined as that quantity of snowmelt which results as streamflow. The flow generated during a given melt interval is obtained from the discharge hydrograph by means of the recession curve. In general,

Table 1.--Estimated peak water equivalent and subsequent precipitation on Fool Creek, 1952

Aspect and zone[1]	Mean elevation	Peak water equivalent	Precipitation subsequent to peak water equivalent										
			Apr. 25	May 1	May 24	May 29	June 5	June 12	June 20	June 27	July 1	Total	Total seasonal
	Feet	Inches											
EAST ASPECT:													
1	9,750	14.4	0.92	0.56	1.03	1.48	0.24	1.01	0.05	0.11	0.33	5.73	20.1
2	9,900	15.6	.88	.57	1.03	1.46	.24	1.00	.05	.11	.32	5.66	21.3
3	10,050	16.8	.39	.58	1.04	1.44	.24	.99	.05	.12	.30	5.64	22.4
4	10,190	18.0	.87	.60	1.03	1.42	.25	.98	.05	.12	.28	5.60	23.6
5	10,310	19.0	.85	.72	1.03	1.40	.25	.96	.05	.12	.28	5.63	24.6
6	10,410	19.8	.84	.81	1.09	1.40	.50	.81	.05	.13	.23	5.86	25.7
7	10,510	20.5	.83	.90	1.11	1.38	.81	.45	.05	.13	.22	5.88	26.4
8	10,620	21.4	.82	1.00	1.14	1.36	1.20	.06	.05	.14	.20	5.97	27.4
9	10,850	23.2	.80	1.22	1.43	1.34	1.22	.06	.05	.15	.18	6.45	29.6
10	11,100	25.2	.78	1.46	1.73	1.28	1.24	.06	.05	.16	.14	6.90	32.1
Total		193.9	8.48	8.42	11.66	13.96	6.19	6.38	.50	1.29	2.45	59.33	253.2
Mean		19.4	.85	.84	1.17	1.40	.62	.64	.05	.13	.24	5.93	25.3
WEST ASPECT:													
1	9,810	12.6	.90	.10	1.30	1.41	.41	.95	.10	.10	.30	5.55	18.1
2	10,025	14.6	.92	.11	1.49	1.40	.47	1.05	--	.11	.28	5.83	20.4
3	10,140	16.1	.89	.33	1.54	1.39	.61	1.00	--	.12	.27	6.15	22.2
4	10,350	17.6	.85	.70	1.33	1.38	.92	.57	--	.12	.26	6.13	23.7
5	10,540	19.3	.81	1.16	1.09	1.37	1.28	.08	--	.13	.25	6.17	25.5
6	10,720	20.9	.78	1.26	1.32	1.36	1.32	.06	--	.14	.24	6.48	27.4
7	10,865	22.2	.75	1.29	1.58	1.35	1.33	.06	--	.15	.23	6.36	28.6
8	10,985	23.4	.72	1.32	1.75	1.34	1.34	.06	--	.15	.22	6.90	30.3
9	11,110	24.5	.68	1.35	1.93	1.34	1.35	.06	--	.16	.21	7.08	31.6
10	11,280	26.1	.66	1.40	2.19	1.33	1.36	.06	--	.17	.20	7.37	33.5
Total		197.3	8.04	9.02	15.52	13.67	10.39	3.95	.10	1.35	2.46	64.02	261.3
Mean		19.7	.80	.90	1.55	1.37	1.04	.39	.01	.13	.25	6.40	26.1

[1]Each zone represents 10 percent of the watershed area.

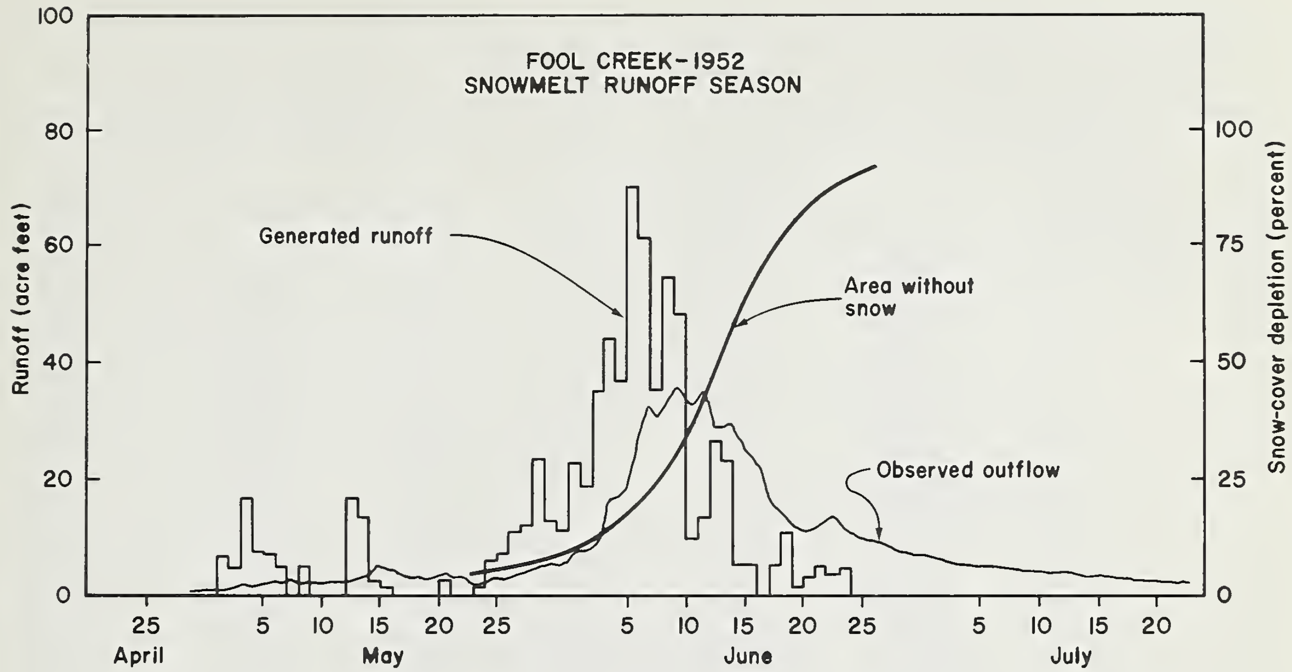


Figure 5.--Summary of snow-cover depletion, generated runoff, and observed outflow from Fool Creek, 1952 snowmelt runoff season.

the procedure for deriving generated flows is to (1) compute the volume observed during the interval, (2) add the volume beneath the recession curve (storage volume) at the end of the interval, and (3) subtract the storage volume which existed on the watershed at the beginning of the interval. The procedure and reasoning behind this approach is discussed in detail by the U.S. Army (1956) and Garstka et al. (1958). Table 2 summarizes flows generated during each snowmelt day for the 1952 runoff season.

Precipitation Input and Melt

Indices of precipitation input and ablation were derived by means of "snow charts" proposed by the Corps of Engineers (U.S. Army 1956). In this procedure, average values of snowpack water equivalents on the various snowcourses were plotted according to their respective elevations and weighted according to the area-elevation curve. Precipitation after peak snowpack water equivalent was measured by a network of 15 standard 8-inch gages along the figure-eight snowcourse.

Deadhorse and Lexen Watersheds

Snowpack Depletion

Deadhorse and Lexen Creek (see fig. 2) flow east and drain 667 and 306 acres, respectively. Elevations range from 9,450 feet at Deadhorse stream gage and 9,850 at Lexen gage to 11,600 feet. In contrast to Fool Creek, these watersheds are steeper, with side slopes averaging almost 40 percent. The north and south exposures, particularly at the lower elevations, provide unequal heat supply.

Aerial photography has been used to observe snow-cover depletion since 1964. Photos are taken at about 10-day intervals after snowmelt begins on Deadhorse and Lexen. Oblique photographs were taken through the 1964 melt season. In 1965 and subsequent years, vertical photographs with an approximate photo scale of 500 feet to the inch were obtained in cooperation with the Office of Atmospheric Water Resources, USDI Bureau of Reclamation.

The extent of snow cover on the photographs was estimated visually with the aid of a folding stereoscope; these estimates were transposed to

Table 2.--Seasonal generated runoff above 0.3 c.f.s. baseflow from Fool Creek during 1952 snowmelt runoff season

Month and day	Generated runoff Daily	Generated runoff Cumulative		Month and day	Generated runoff Daily	Generated runoff Cumulative	
	Acre-ft.	Acre-ft.	Percent		Acre-ft.	Acre-ft.	Percent
May				June			
2	7.02	7.07	1.0	3	34.98	250.60	35.1
3	4.59	11.66	1.6	4	44.10	294.70	41.3
4	16.82	28.48	4.0	5	37.45	332.15	46.5
5	7.71	36.20	5.1	6	69.66	401.81	56.3
6	7.14	43.34	6.1	7	61.00	462.81	64.9
7	5.12	48.45	6.8	8	35.17	497.98	69.8
9	5.18	53.64	7.5	9	53.39	551.37	77.3
13	16.52	70.16	9.8	10	47.96	599.33	84.0
14	13.69	83.85	11.8	11	9.74	609.08	85.4
15	1.88	85.73	12.0	12	13.61	622.69	87.3
16	1.44	87.17	12.2	13	26.33	649.02	91.0
21	2.72	89.89	12.6	14	23.03	672.05	94.2
24	.89	90.78	12.7	15	5.06	677.11	94.9
25	6.19	96.97	13.6	16	4.94	682.06	95.6
26	6.79	103.75	14.5	18	5.41	687.47	96.3
27	10.96	114.72	16.1	19	10.97	698.43	97.9
28	11.79	126.50	17.7	20	1.02	699.46	98.0
29	23.64	150.14	21.0	21	2.27	701.72	98.3
30	12.81	162.96	22.8	22	4.58	706.31	99.0
31	11.25	174.20	24.4	23	3.11	709.41	99.4
June							
1	23.25	197.46	27.7	24	4.17	[1]713.58	100.0
2	18.17	215.63	30.2				

[1]Total seasonal generated runoff; observed outflow to June 24, 1952, 578.59 acre-feet.

subdivided base maps of each watershed. As on Fool Creek, watershed subunits were delimited on the basis of orientation, vegetation, and slope steepness. The total watershed snow cover was determined by computing a weighted average based on the area and extent of snow cover in these subunits. For reasons discussed below, Deadhorse Creek was divided into an upper and lower basin (fig. 6).

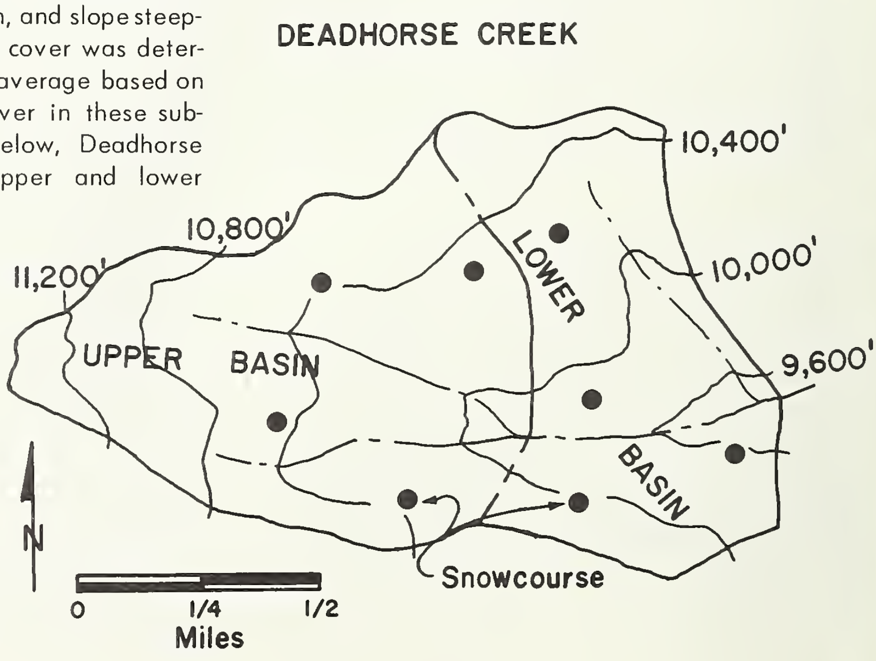


Figure 6.--Snowcourse locations on Deadhorse Creek, 1969.

Runoff

Streamflow from Deadhorse and Lexen watersheds is gaged by 120° V-notch weirs. Snowmelt runoff hydrographs for the 1969 season are plotted in figure 7. Flows generated during five of the six time intervals in figure 7 are summarized in table 3. Seasonal totals are based on flows gen-

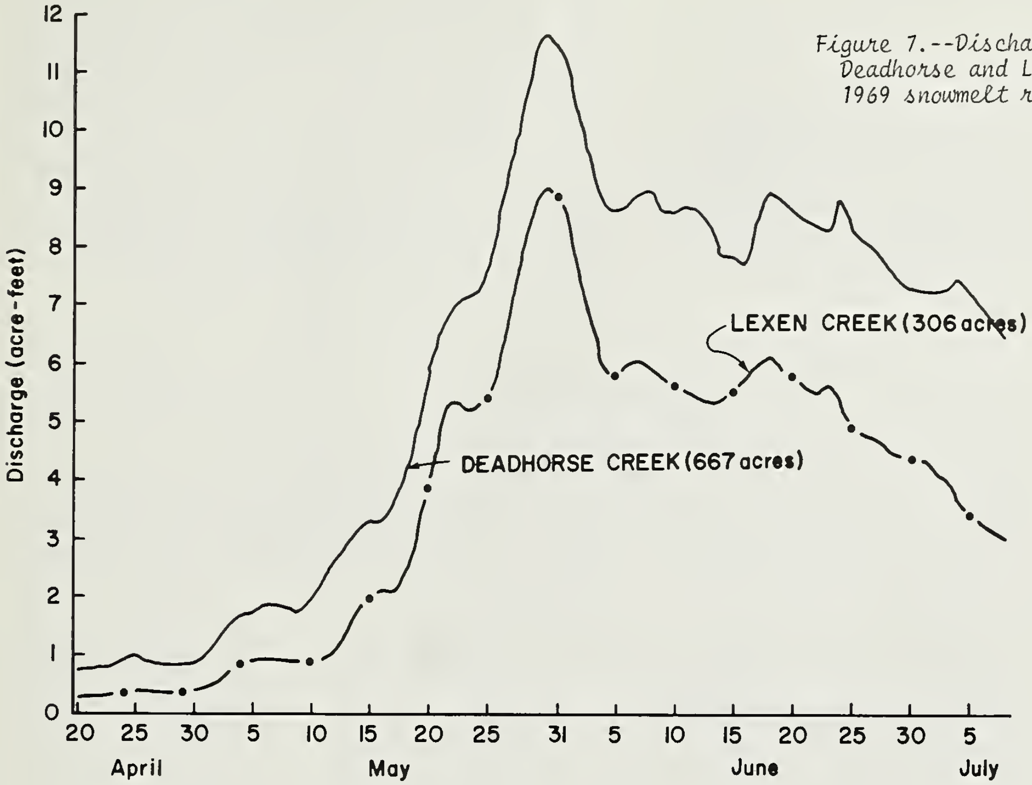


Figure 7.--Discharge hydrographs of Deadhorse and Lexen Creeks during 1969 snowmelt runoff season.

Table 3.--Seasonal generated runoff[1] from Deadhorse and Lexen Creeks during 1969 snowmelt runoff season

Interval	Generated runoff on-- Deadhorse Creek: During interval	Deadhorse Creek: Cumulative		Lexen Creek: During interval	Lexen Creek: Cumulative	
	Acre-ft.	Acre-ft.	Percent	Acre-ft.	Acre-ft.	Percent
April 16 to April 30	24.5	24.5	5.7	10.6	10.6	3.6
April 30 to May 21	179.1	203.6	47.6	189.2	199.8	67.2
May 21 to May 28	148.9	352.5	82.3	42.2	242.0	81.3
May 28 to June 4	25.4	377.9	88.3	15.5	257.5	86.5
June 4 to June 11	50.1	[2]428.0	100.0	40.0	[3]297.5	100.0

[1]Above an assumed constant baseflow of 0.2 and 0.1 cubic foot per second on Deadhorse and Lexen Creeks, respectively.
[2]Total seasonal generated runoff; observed outflow to June 11, 1969, 368.1 acre-feet.
[3]Total seasonal generated runoff; observed outflow to June 11, 1969, 252.0 acre-feet.

erated through June 11. The unusually high precipitation and resultant streamflow during the last half of June were not included in these summaries, since almost all the seasonal snowpack had already melted.

Precipitation Input and Melt

Estimates of peak seasonal water equivalent and ablation during the melt season were derived from weekly measurements of a network of eight snowcourses, each with eight sample points, on the major aspects of Deadhorse Creek (see fig. 6). Average snowcourse water equivalents were plotted according to elevation; these relationships were used to estimate the amount of snowpack in each of 22 watershed subunits. A weighted index of areal water equivalent was then computed, based on the estimated snowpack water equivalents in each subunit. Precipitation input after peak seasonal snowpack accumulation was estimated from weekly measurements of a network of seven standard 8-inch gages spaced along the access road shown in the lower lefthand corner of figure 2. An arithmetic average of the seven gages was assumed to be the best estimate of areal precipitation on Deadhorse Creek. Peak water equivalent and precipitation during snowmelt are summarized in table 4.

Table 4.--Estimated peak seasonal water equivalent and subsequent precipitation on Deadhorse Creek, 1969 snowmelt season

Watershed subunit	Median elevation	Peak water equivalent	Precipitation subsequent to peak [1]								
			Apr. 16	Apr. 30	May 7	May 14	May 21	May 28	June 4	June 11	Total
	Feet	Inches									
LOWER BASIN:											
I	9,650	10.7	0.8	0.8	1.8	0.1	1.0	0.3	0.2	0.9	16.6
II	9,700	11.5	.8	.8	1.8	.1	1.0	.3	.2	.9	17.4
III	9,850	12.0	.8	.8	1.8	.1	1.0	.3	.2	.9	17.9
IV	9,900	12.0	.8	.8	1.8	.1	1.0	.3	.2	.9	17.9
V	10,000	12.5	.8	.8	1.8	.1	1.0	.3	.2	.9	18.4
VI	9,950	12.5	.8	.8	1.8	.1	1.0	.3	.2	.9	18.4
VII	10,000	13.0	.8	.8	1.8	.1	1.0	.3	.2	.9	18.9
VIII	10,100	13.0	.8	.8	1.8	.1	1.0	.3	.2	.9	18.9
XVII	10,600	14.0	.8	.8	1.8	.1	1.0	.3	.2	.9	19.9
XVIII	10,250	12.7	.8	.8	1.8	.1	1.0	.3	.2	.9	18.6
XVIII-A	9,900	10.5	.8	.8	1.8	.1	1.0	.3	.2	.9	16.4
XIX	10,050	11.7	.8	.8	1.8	.1	1.0	.3	.2	.9	17.6
XX	10,350	14.0	.8	.8	1.8	.1	1.0	.3	.2	.9	19.9
XXI	9,950	10.7	.8	.8	1.8	.1	1.0	.3	.2	.9	16.6
Weighted average:		11.9	.8	.8	1.8	.1	1.0	.3	.2	.9	17.8
UPPER BASIN:											
IX	10,250	14.5	.8	.8	1.8	.1	1.0	.3	.2	.9	20.4
X	10,400	14.7	.8	.8	1.8	.1	1.0	.3	.2	.9	20.6
XI	10,200	13.7	.8	.8	1.8	.1	1.0	.3	.2	.9	19.6
XII	10,800	16.0	.8	.8	1.8	.1	1.0	.3	.2	.9	21.9
XIII	11,150	18.0	.8	.8	1.8	.1	1.0	.3	.2	.9	23.9
XIV	10,850	15.0	.8	.8	1.8	.1	1.0	.3	.2	.9	20.9
XV	10,550	15.0	.8	.8	1.8	.1	1.0	.3	.2	.9	20.9
XVI	10,350	14.0	.8	.8	1.8	.1	1.0	.3	.2	.9	19.9
Weighted average:		15.3	.8	.8	1.8	.1	1.0	.3	.2	.9	21.2
Total weighted average:		13.7	.8	.8	1.8	.1	1.0	.3	.2	.9	19.6

[1]Average of seven standard 8-inch gages along access road.

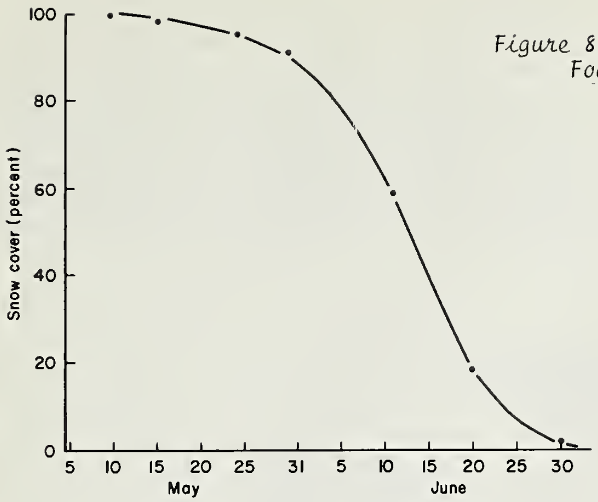


Figure 8.--Sequence of snow-cover depletion on Fool Creek, 1952 snowmelt season.

Analysis and Results

Sequence of Snow-Cover Depletion

The sequence of snow-cover depletion on Fool Creek, Deadhorse, and Lexen watersheds is plotted in figures 8-10. Compared to Lexen Creek, areal depletion of the snowpack on Deadhorse Creek starts earlier as the result of advanced snowmelt on the low-elevation south slopes. The rate of depletion in the upper basin of Deadhorse Creek (fig. 10) is similar to that of Lexen.

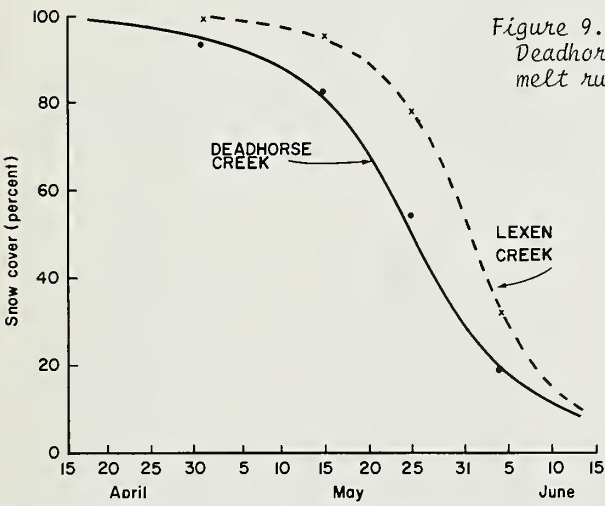


Figure 9.--Sequence of snow-cover depletion on Deadhorse and Lexen watersheds, 1969 snowmelt runoff season.

The dates when watershed subunits became bare of snow were estimated to obtain a more complete picture of snowpack depletion. This sequence was approximated by considering an intermediate extent of snow cover (Miller 1953). The dates were expressed as the number of days after April 30, when snowmelt runoff began on Fool Creek in 1952 and on Deadhorse and Lexen in 1967.

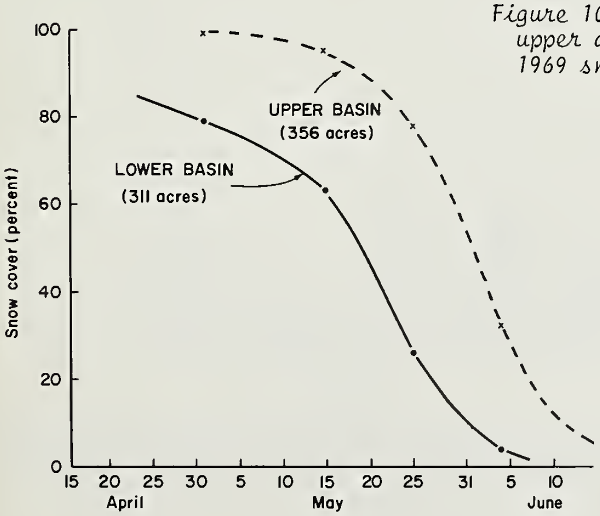


Figure 10.--Sequence of snow-cover depletion on upper and lower basins of Deadhorse Creek, 1969 snowmelt runoff season.

The combined effects of elevation, forest cover, and contrasting orientation on snow-cover depletion are illustrated by the average date when snow cover was reduced to 60 percent of the watershed area:

	Fool Creek	Deadhorse	Lexen
Year	1952	1967	1967
Number of subunits	6	22	11
Number of days after April 30:			
Average	36	28	36
Range	35-53	1-52	22-51
Standard deviation	7	14	9

The snowpack depletion season was longer and depletion rates were more widely dispersed around the watershed mean on Deadhorse Creek. The delayed and shorter snow-cover depletion season on Lexen is apparently more comparable to Fool Creek, since large areas of these watersheds become bare of snow simultaneously.

Snowmelt

Although the following discussion refers primarily to figures 11 and 12, it should be considered to apply to other years. These data are the best estimates available of relative snowmelt according to aspect and elevation at the Fraser Experimental Forest.

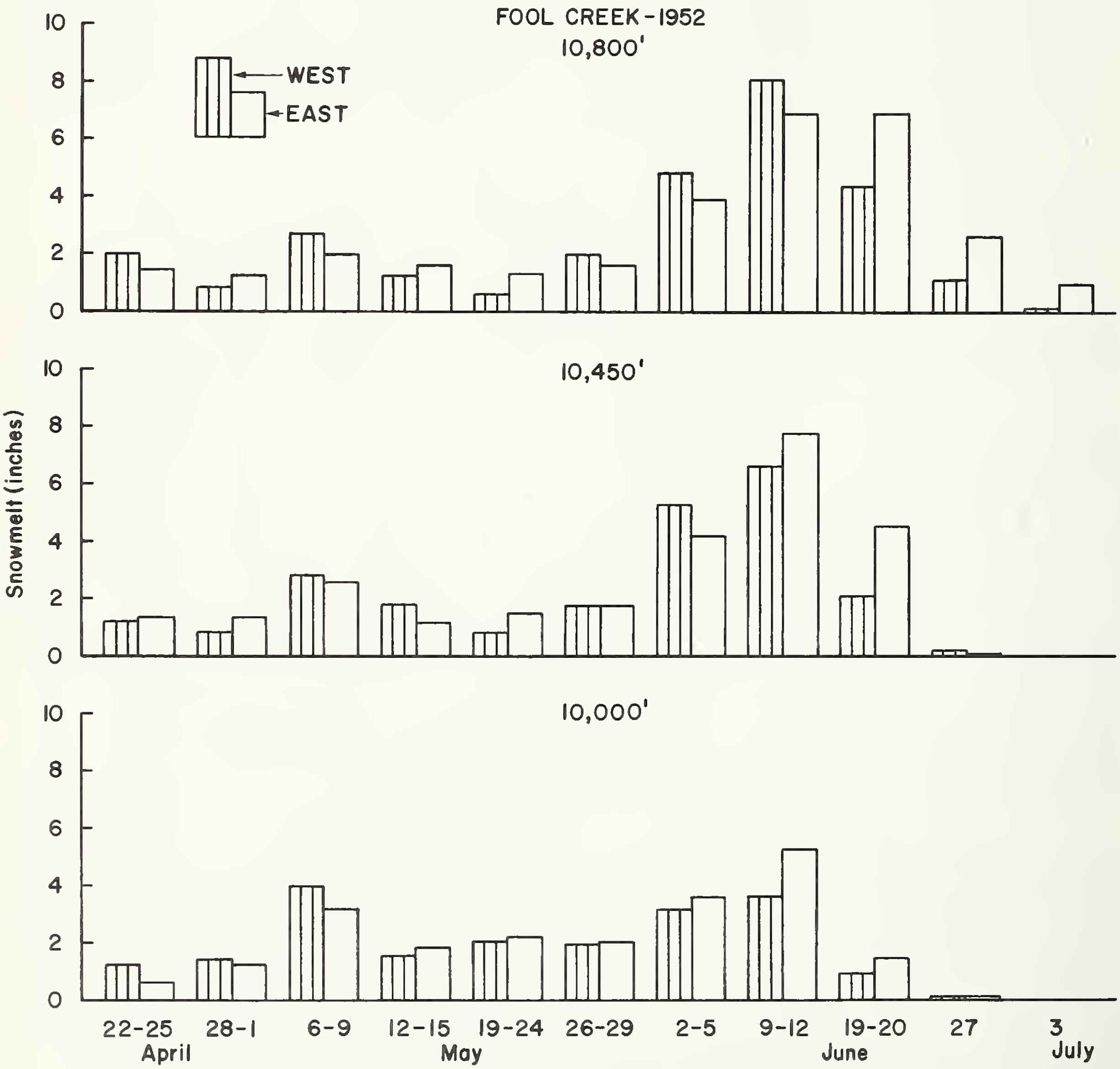


Figure 11.--Relative snowmelt rates at low, intermediate, and high elevations on the east- and west-facing aspects of Fool Creek. The individual bars represent snowmelt corrected for precipitation recorded between each snow-survey interval.

The analysis of peak snowpack accumulation on Fool Creek showed essentially the same average water equivalent on the east- and west-facing aspects (see table 1). Both aspects retained about the same average water equivalent throughout the snowmelt season. Snowpack melt rates were generally similar on both aspects at all elevations on Fool Creek watershed (fig. 11). Areal snowmelt corrected for precipitation after peak water equivalent is summarized in table 5.

Snowpack melt rates differed considerably between the low-elevation north and south slopes of Deadhorse watershed (fig. 12). This agrees with the results of Garstka et al. (1958), who reported that, at 9,500 feet on a watershed adjacent to Deadhorse Creek, melt rates on the south slope

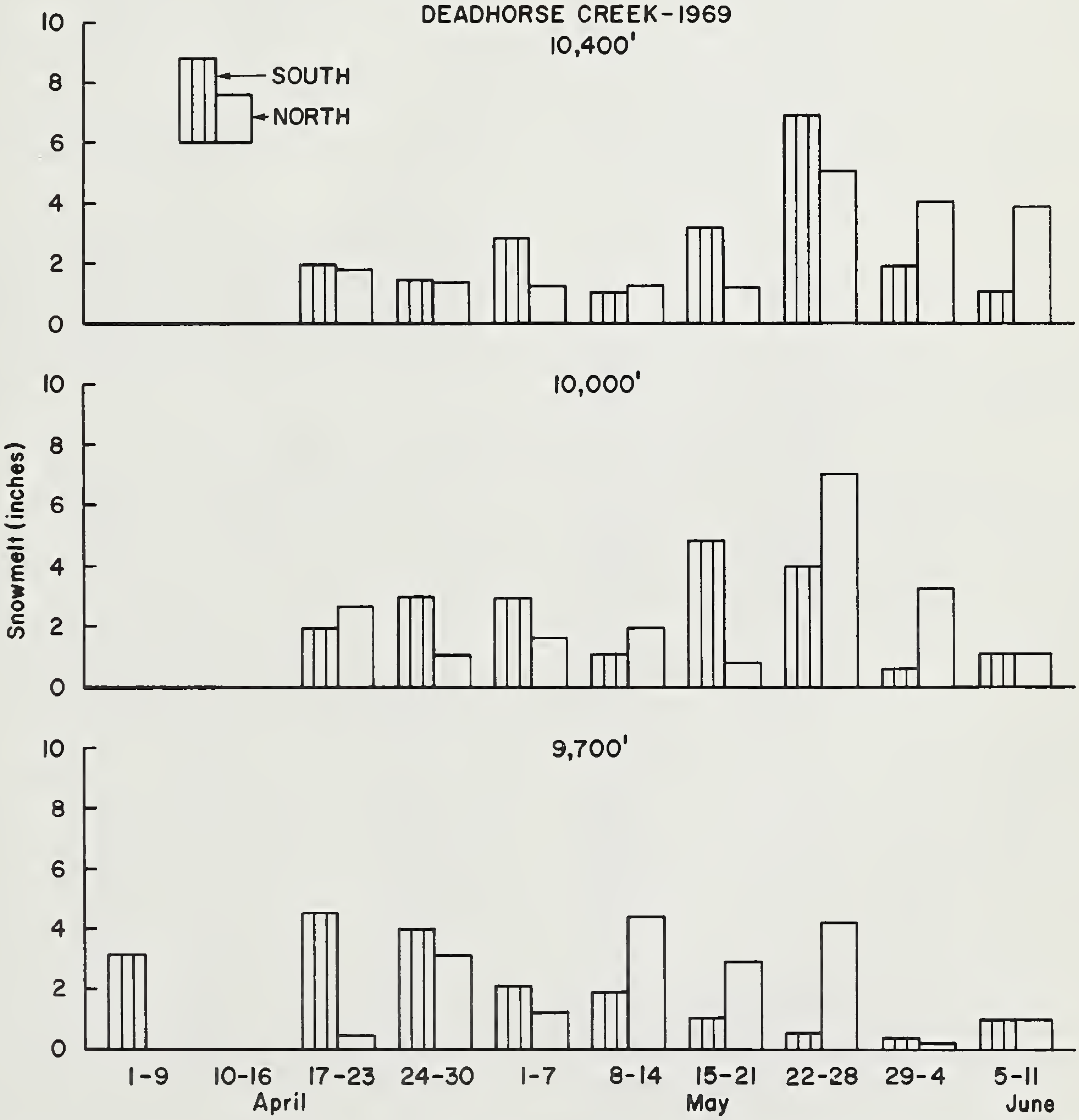


Figure 12.--Relative snowmelt rates at low, intermediate, and high elevations on the north- and south-facing aspects of Deadhorse Creek. The individual bars represent snowmelt corrected for precipitation recorded between each snow-survey interval.

Table 5.--Areal snowmelt on study watersheds, corrected for precipitation subsequent to peak water equivalent

Watershed and measurement periods	Water equivalent, beginning of period	During interval			Cumulative snowmelt	
		Snowmelt	Precipitation	Total		
		- - - - - - Inches - - - - - - -			Inches	Percent
FOOL CREEK, 1952:						
April 16-25	19.6	0.1	0.82	0.92	0.92	3.6
April 25-May 1	19.5	.7	.87	1.57	2.49	9.7
May 1-24	18.8	4.4	1.39	5.79	8.28	32.1
May 24-29	14.4	.5	1.38	1.88	10.16	36.8
May 29-June 5	13.9	3.4	.86	4.26	14.42	55.9
June 5-12	10.5	6.2	.50	6.70	21.12	81.8
June 12	4.0					
Seasonal total[1]				25.76		100.0
DEADHORSE CREEK, 1969:						
Total watershed						
April 9-22	13.7	1.4	.8	2.2	2.2	11.2
April 23-29	12.3	1.5	.8	2.3	4.5	23.0
April 30-May 6	10.8	1.6	1.8	3.4	7.9	40.3
May 7-13	9.2	.2	.1	.3	8.2	41.8
May 14-20	9.0	1.5	1.0	2.5	10.7	54.6
May 21-27	7.5	4.8	.3	5.1	15.8	80.6
May 28-June 3	2.7	1.7	.2	1.9	17.7	90.3
June 4-10	1.0	1.0	.9	1.9	19.6	100.0
June 11	0					
Upper basin[2]						
April 9-22	15.3	1.1	.8	1.9	1.9	4.7
April 23-29	14.2	1.1	.8	1.9	3.8	17.9
April 30-May 6	13.1	1.5	1.8	3.3	7.1	33.5
May 7-13	11.6	0	.1	.1	7.2	34.0
May 14-20	11.6	1.0	1.0	2.0	9.2	43.4
May 21-27	10.6	6.0	.3	6.3	15.5	73.1
May 28-June 3	4.6	2.6	.2	2.8	18.3	86.3
June 4-10	2.0	2.0	.9	2.9	21.2	100.0
June 11	0					
Lower basin						
April 9-22	11.9	1.8	.8	2.6	2.6	14.6
April 23-29	10.1	1.9	.8	2.7	5.3	29.8
April 30-May 6	8.2	1.8	1.8	3.6	8.9	50.0
May 7-13	6.4	.7	.1	.8	9.7	54.5
May 14-20	5.7	1.7	1.0	2.7	12.4	69.7
May 21-27	4.0	3.4	.3	3.7	16.1	90.4
May 28-June 3	.6	.6	.2	.8	16.9	94.9
June 4-10	0		.9	.9	17.8	100.0
June 11	0					

[1]As derived from table 1.
[2]Data collected from upper basin were identical with those from Lexen Creek.

peaked much earlier than on the opposite north slope. It should be noted, however, that the time lag between maximum snowmelt rates on the north and south slopes diminished with increasing elevation. This effect is also seen in our study—dispersion of areal snowpack depletion rates around the watershed mean on high-elevation Lexen Creek is considerably less than on Deadhorse Creek. Gary and Coltharp (1967) similarly observed that snowmelt rates were about the same on high-elevation north and south slopes in northern New Mexico. Areal melt on Deadhorse Creek corrected for precipitation after peak water equivalent is summarized in table 5.

Relative Water Yields from Upper and Lower Deadhorse Creek

Streamflow from Lexen Creek can vary from 60 percent of Deadhorse in high runoff years to almost 90 percent in low runoff years (table 6). Because this variation has important implications for watershed management, water yields were compared further.

Table 6.--Relative seasonal water yields from Deadhorse and Lexen watersheds, 1956-69

Year	Generated runoff[1]		Ratio of runoff,
	Deadhorse Creek	Lexen Creek	Lexen:Deadhorse
	- - Acre-feet - -		Percent
1956	647.8	397.0	61
1957	1041.9	623.9	60
1958	688.8	424.6	62
1959	533.4	345.8	65
1960	595.2	384.0	64
1961	269.3	233.0	87
1962	943.9	580.0	61
1963	139.7	120.5	86
1964	339.5	275.4	82
1965	628.3	383.0	61
1966	213.3	186.7	88
1967	463.0	329.3	71
1968	439.1	328.9	75
1969	428.0	297.5	69
Mean			70

[1]Above an assumed constant baseflow of 0.2 and 0.1 cubic foot per second on Deadhorse and Lexen Creeks, respectively.

Deadhorse and Lexen watersheds are contiguous and physiographically similar. Early spring snow surveys have shown that snow accumulation on Lexen is similar to that observed in the high elevations of Deadhorse. Moreover, the rate of snow-cover depletion in the higher elevations of Deadhorse Creek is identical to that of Lexen Creek (figs. 9, 10).

In this analysis, it was assumed that flows generated from Lexen Creek correspond to like volumes from Deadhorse Creek above 9,850 feet (the elevation of Lexen Creek stream gage). On Deadhorse watershed, the apparent drainage area above this elevation is 356 acres or 53.3 percent of the watershed total. Relative contributions of snowmelt runoff from upper and lower Deadhorse Creek are summarized for several intervals during the 1969 snowmelt runoff season in table 7. Data

Table 7.--Relative contributions to streamflow from upper and lower basins of Deadhorse Creek during the 1969 snowmelt runoff season

Interval 1969	Runoff generated during interval		
	Deadhorse Creek	Upper Deadhorse[1]	Lower Deadhorse[2]
	- - - - - - Inches - - - - - - -		
April 20-May 21	3.6	5.4	1.6
May 21-May 28	2.7	3.9	1.3
May 28-June 4	.5	.6	.4
June 4-June 11	.9	1.5	.2
Total	7.7	11.4	3.5

[1]Measurements taken on Lexen Creek were transposed to upper Deadhorse Creek since assumption is that flows generated from Lexen Creek are comparable. Upper Deadhorse Creek (above 9,850 feet) has an estimated drainage area of 356 acres or 53.3 percent of the watershed total.

[2]Lower Deadhorse Creek has an estimated drainage area of 311 acres or 46.7 percent of the watershed total.

in the summary were obtained by the expression

$$D = 0.53L + 0.47\,D_L \text{ or}$$

$$D_L = \frac{D - 0.53L}{0.47}$$

where

D_L = the generated flow from lower Deadhorse Creek (inches)

D = the generated flow from the entire Deadhorse Creek watershed (inches)

L = the flow generated from Lexen Creek (inches)

As expected, resultant streamflow from snowmelt on lower Deadhorse Creek was less than 30 percent of that generated from the upper basin, even though total precipitation below 9,850 feet was about 80 percent of the high-elevation input (see table 4). Relative water yields from the upper and lower basins for each year of record (summarized in table 8) are plotted in figure 13. Low-elevation water yields apparently can vary from near zero for poor runoff years to a maximum during good years of about 50 percent of the flow generated from the upper basin.

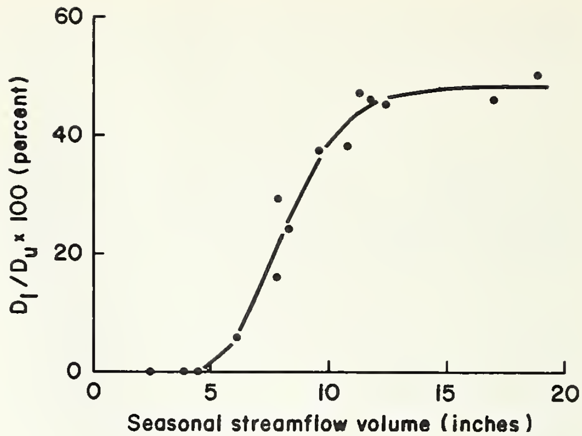


Figure 13.--Contribution of snowmelt runoff from lower Deadhorse (expressed as a percentage of that from upper Deadhorse) as a function of seasonal streamflow from the entire watershed.

Table 8.--Relative seasonal contributions of snowmelt runoff from upper and lower Deadhorse Creek

Year	Generated runoff: Deadhorse Creek	Generated runoff: Upper Deadhorse[1]	Generated runoff: Lower Deadhorse	Ratio of runoff, Lower:Upper
	Inches	Inches	Inches	Percent
1956	11.7	15.6	7.2	46
1957	18.8	24.5	12.3	50
1958	12.4	16.7	7.5	45
1959	9.6	13.6	5.0	37
1960	10.7	15.1	5.7	38
1961	4.8	9.1	(-0.1)	0
1962	17.0	22.8	10.4	46
1963	2.5	4.7	0	0
1964	6.1	10.8	.7	6
1965	11.3	15.0	7.1	47
1966	3.8	7.3	(-0.2)	0
1967	8.3	12.9	3.1	24
1968	7.9	12.9	2.1	16
1969	7.7	11.4	3.5	31
Mean	9.5	13.7	4.7	34

[1]Measurements taken on Lexen Creek were transposed to upper Deadhorse Creek since assumption is that flows generated from Lexen are comparable.

Water Balance

Watershed efficiency (generated runoff expressed as a percentage of snowmelt input) averaged 48 percent during the 1952 runoff season on Fool Creek (fig. 14). This compares with an average 39 percent for the period 1943-54 (table 9). In 1952, snowmelt averaged 2.9 inches before any streamflow was generated. Between May 1 and May 29, 37 percent of the input was yielded as streamflow. During highest streamflow, efficiency averaged 73 percent, then decreased markedly until the end of snowmelt. It should be noted that more than 90 percent of the seasonal runoff volume was generated before 50 percent of the watershed became bare of snow. This is considerably more than previously reported on Beaver Creek in Arizona by Ffolliott and Hansen (1968). During highest streamflow on Fool Creek (May 29-June 12), areal snow cover decreased from 90 to 55 percent. Streamflow produced during this time interval comprised 70 percent of the seasonal volume. After the peak, the residual snowpack which covered 45 percent of Fool Creek produced only 13 percent of the seasonal runoff.

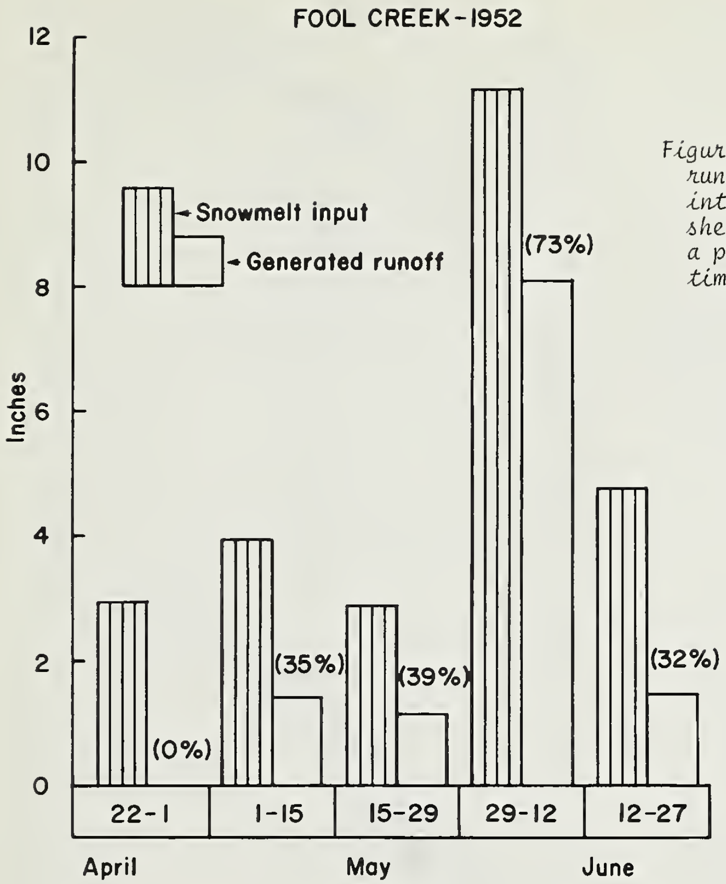


Figure 14.--Comparison of snowmelt and generated runoff from Fool Creek for five snow-survey intervals during the 1952 melt season. Watershed efficiency (generated runoff expressed as a percentage of snowmelt input) during each time interval is shown in parentheses.

Table 9.--Fool Creek water balance for 1943-54 record period

Year	Peak water equivalent	Subsequent precipitation	Total[1]	Generated runoff[2]	Efficiency[3]
	Inches				Percent
1943	17.4	7.8	25.2	9.8	38.9
1944	13.9	9.3	23.2	6.3	27.2
1945	--	--	--	--	--
1946	11.5	4.3	15.8	7.4	46.8
1947	16.2	9.4	25.6	11.0	43.0
1948	13.9	5.0	18.9	7.8	41.3
1949	14.0	7.2	21.2	7.9	37.3
1950	14.1	6.4	20.5	7.6	37.1
1951	18.4	6.6	25.0	10.7	42.8
1952	19.4	5.6	25.0	12.0	48.0
1953	11.4	8.2	19.6	7.9	40.3
1954	9.1	3.9	13.0	2.4	18.5
Mean	14.5	6.7	21.2	8.2	38.7

[1]Index of total precipitation input determined from the figure-eight snowcourse which traverses the watershed.
[2]Above an assumed constant baseflow of 0.3 cubic foot per second.
[3]Generated runoff expressed as a percentage of snowmelt input.

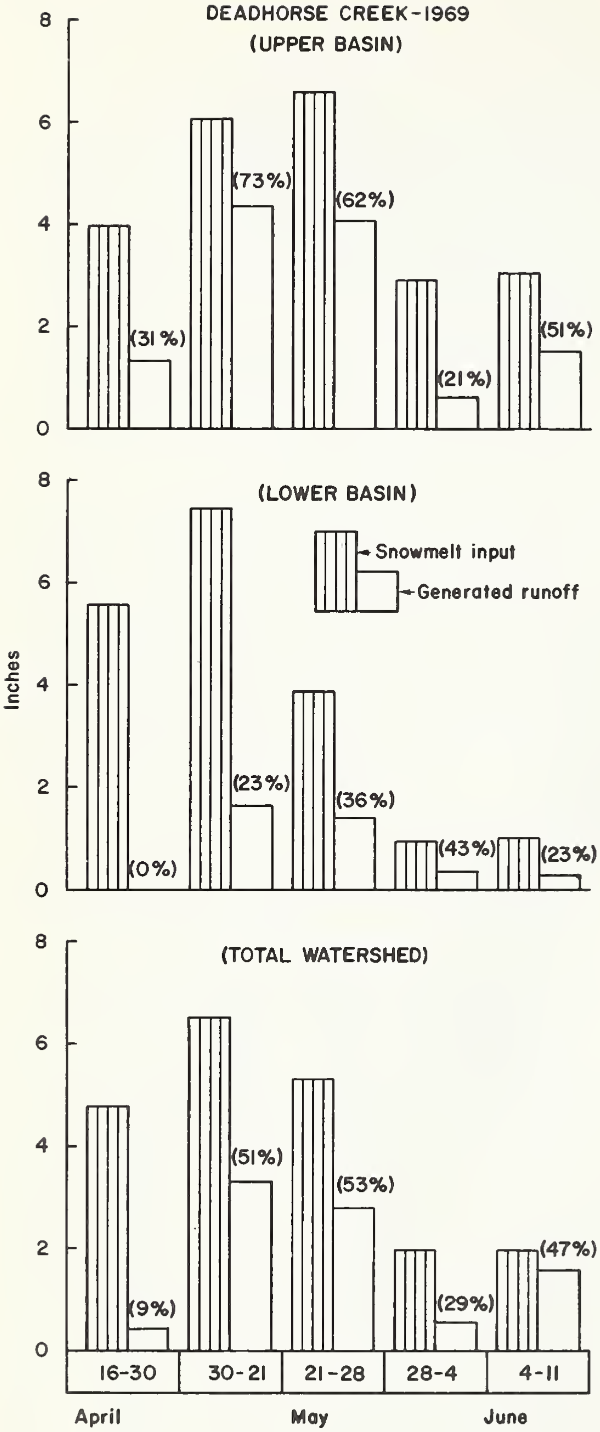


Figure 15.--
Comparison of snowmelt and generated runoff from Deadhorse Creek for five snow-survey intervals during the 1969 melt season. Watershed efficiency (generated runoff expressed a percentage of snowmelt input) during each time interval is shown in parentheses.

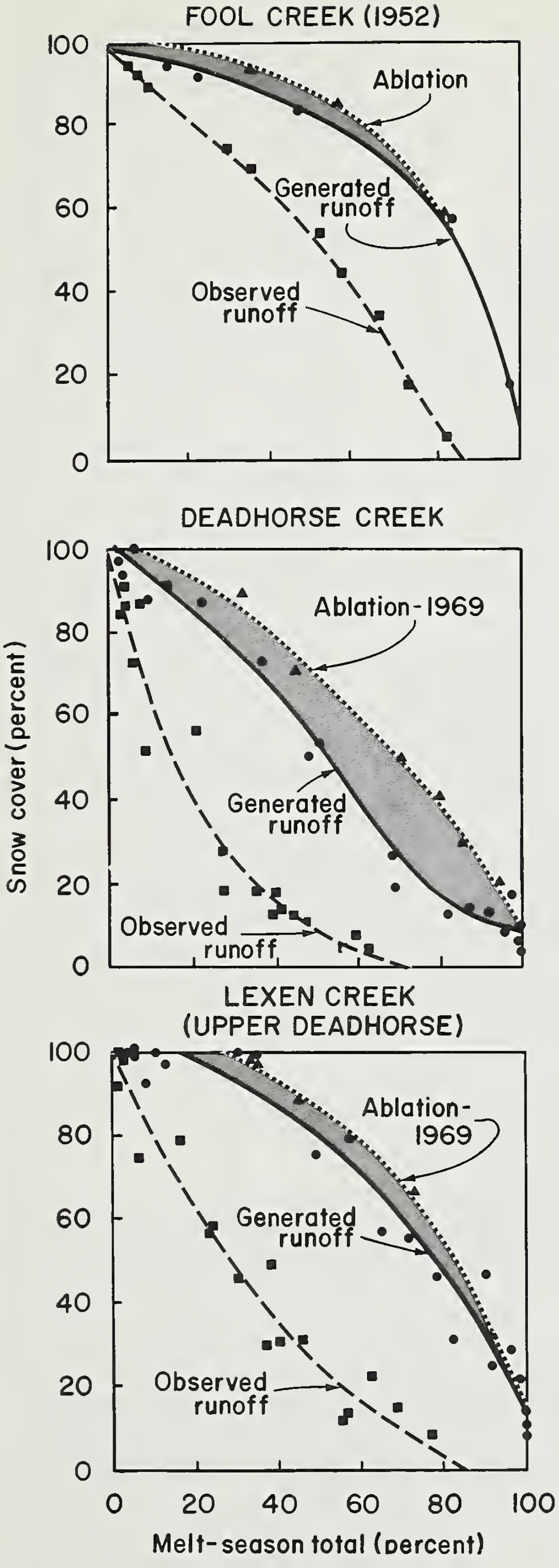
Deadhorse watershed averaged 39 percent efficiency; the upper basin averaged 54 percent, while the lower basin averaged only 20 percent (fig. 15). Less than 15 percent of the snowmelt prior to May 21 in the lower basin was converted to streamflow compared with 59 percent in the upper basin. On May 21, snow cover in the upper basin occupied approximately 90 percent of the area, whereas in the lower basin, more than half the area was bare. Snow cover was complete on the north slopes in both the upper and lower basins at this time. After May 21, streamflow accounted for 1.9 inches of the estimated 3.5 inches generated from the lower basin. Precipitation input was 5.4 inches. It is important to note that, in the upper basin, almost 90 percent of the seasonal runoff volume was generated before 60 percent of the area became bare of snow. Furthermore, more than 80 percent of the upper basin was still covered with snow when seasonal snowmelt rates reached their peak.

The high efficiencies on Lexen Creek (and similarly, upper Deadhorse) and Fool Creek are apparently the result of (1) almost complete snow cover at the time when seasonal snowmelt rates are maximum on all aspects, (2) a delayed and short snow-cover depletion season, and (3) relatively low recharge and evapotranspiration losses.

Snow-Cover Depletion in Relation to Runoff and Melt

Snowpack depletion is plotted as a function of accumulated melt (ablation) and observed and generated runoff in figure 16 for the period 1964-68. Each watershed has a characteristic relationship between snowpack depletion and runoff that apparently does not change appreciably, even though the amount of snowpack and weather conditions which produce runoff each year vary considerably. It is possible that the scatter around the mean curves is the result of annual differences in initial snowpack water equivalent, recharge requirements, and meteorological conditions during snowmelt. However, experimental error may account for a large portion of the variation.

The relationships derived for Lexen (upper Deadhorse) resemble those of Fool Creek (before harvest cutting) due to their similar snow-cover depletion, snowmelt, and losses. The closer agreement be-



tween the ablation and generated runoff relationships on Fool Creek and Lexen (upper Deadhorse) reflects accelerated depletion of the snow cover after most of the snowpack water equivalent has melted. This provides for more efficient conversion of snowmelt runoff to streamflow.

On Deadhorse Creek, the large differences in snowmelt rates and high recharge and evapotranspiration losses in the lower basin (see figs. 12, 15) are reflected by the conspicuous displacement between the generated runoff and ablation curves. When the area of snow cover decreases rapidly with increasing ablation and runoff, as in the lower basin of Deadhorse watershed, less efficient conversion of snowmelt to streamflow is indicated.

Summary

Snowmelt and resultant snowpack depletion and water yield were studied on three experimental watersheds in the Fraser Experimental Forest. Drainage areas within the following three physiographic complexes were analyzed: (1) forested, with generally east- and west-facing aspects between 9,600 and 11,500 feet (Fool Creek); (2) forested, with predominantly north- and south-facing aspects between 9,450 and 9,850 feet (lower Deadhorse Creek); and (3) forested, with primarily north and south aspects, but with the drainage area between 9,850 and 11,600 feet (Lexen and upper Deadhorse Creeks). Deadhorse and Lexen watersheds are contiguous. The analyses were based primarily on data collected in 1952 from Fool Creek, and in 1969 from Deadhorse and Lexen watersheds.

On Deadhorse Creek, the snowpack depletion season was relatively long, and depletion rates varied widely on subunits within the watershed. In contrast, on Fool Creek and Lexen, depletion of the snow cover was delayed for some time after the runoff season began, and large areas then became bare of snow simultaneously.

Figure 16.--Snow-cover depletion in relation to runoff and ablation for Fool Creek, Deadhorse, and Lexen (upper Deadhorse) Creek watersheds.

Seasonal snowmelt was essentially the same on the generally east and west aspects of Fool Creek at all elevations. On Deadhorse Creek, snowmelt rates differed greatly between the low-elevation north and south slopes, but the lag between them diminished with elevation.

Relative water yields from the drainage areas above and below 9,850 feet on Deadhorse Creek were estimated by weighted differences between streamflow measured on adjacent Lexen Creek watershed and the total flow of Deadhorse. In 1969, streamflow from snowmelt in the lower basin of Deadhorse was less than 30 percent of that generated from the upper basin, although precipitation input was about 80 percent of the high-elevation input. Fourteen years of streamflow data indicate that water yields from the lower basin can vary from near zero for poor runoff years to a maximum during good years of about 50 percent of the flow generated from the upper basin.

In 1952, efficiency (water yield expressed as a percentage of snowmelt input) averaged 48 percent on Fool Creek, compared to an average 39 percent for an 11-year record period. Efficiency was low when snowmelt runoff first began, and also later in the season when snow became patchy at the higher elevations. Conversion of snowmelt into water yield was highest when streamflow was at its peak. More than 90 percent of the seasonal runoff volume was generated before 50 percent of the watershed was bare of snow. During the period of highest streamflow, areal snow cover decreased only 35 percent and produced 70 percent of the seasonal water yield.

In 1969, overall efficiency on Deadhorse Creek averaged 39 percent; the upper basin averaged 54 percent and the lower basin 20 percent. The upper basin generated almost 90 percent of the seasonal runoff volume before 60 percent of the area became bare of snow.

Comparisons of the water balance and snow-cover depletion on Lexen Creek, upper Deadhorse, and Fool Creek revealed hydrologic similarities among the watersheds in spite of obvious physiographic dissimilarities. These similarities included: (1) almost complete snow cover when seasonal snowmelt rates on all major aspects of the watersheds were maximum; (2) a delayed and short snow-cover depletion season; and (3) relatively low recharge and evapotranspiration losses.

Conclusions

These results are at best crude indices of the energies and physiographic features affecting the disposition of snowmelt runoff. The greatest shortcoming of the study is the questionable accuracy of the areal estimates of precipitation input. The watershed transposition technique employed to determine relative water yields from Deadhorse Creek is also open to criticism. The assumption that upper Deadhorse and Lexen Creeks yield like quantities of streamflow should be verified by field measurements.

Nevertheless, some useful indications have been derived which are pertinent to a better understanding of the hydrology of subalpine watersheds. For example, it appears that in the high water-yielding snow zone, the hydrologic regimes of subunits within even small forested watersheds can vary by several orders of magnitude. Quantitative information of this nature is necessary for determining the potentials on these watersheds for water yield improvement through harvest cutting and/or weather modification.

Because areal snow cover, like streamflow, is an integral measurement, it can be effectively utilized in the identification of watersheds and subunits within watersheds which contribute most (or least) efficiently to streamflow. Also, the index relationships between snowpack depletion and resultant ablation and streamflow derived for experimental watersheds can be effectively used in predicting the hydrology of other areas in the subalpine zone.

Literature Cited

Brown, H. E., and Dunford, E. G.
1956. Streamflow in relation to extent of snow cover in central Colorado. U.S. Forest Serv., Rocky Mt. Forest and Range Exp. Sta., Sta. Pap. 24, 9 p., illus. Fort Collins, Colo.

Ffolliott, Peter F., and Hansen, Edward A.
1968. Observations of snowpack accumulation, melt, and runoff on a small Arizona watershed. U.S.D.A. Forest Serv. Res. Note RM-124, 7 p., illus. Rocky Mt. Forest and Range Exp. Sta., Fort Collins, Colo.

Garstka, W. U., Love, L. D., Goodell, B. C., and Bertle, F. A.
1958. Factors affecting snowmelt and streamflow. U.S. Bur. Reclamation and U.S. Dep. Agr., Forest Serv. 189 p., illus. Washington, D. C.: Govt. Printing Off.

Gary, Howard L., and Coltharp, George B.
1967. Snow accumulation and disappearance by aspect and vegetation type in the Santa Fe Basin, New Mexico. U.S. Forest Serv. Res. Note RM-93, 11 p., illus. Rocky Mt. Forest and Range Exp. Sta., Fort Collins, Colo.

Gross, D. D.
1937. Forecasting mountain water supply by photographing snowfall. Eng. News-Record 119: 310-311, illus.

Hoover, Marvin D.
1967. Forests—where the waterflow starts. U.S. Dep. Agr. Yearb. 1967: 77-79.

____
1969. Vegetation management for water yield. Sess. V: Water balance modification—increasing the yield. Symp. on Water balance in North America [Banff, Alberta, Canada, June 23-26, 1969] Proc. Ser. 7, p. 191-195.

________ and Leaf, Charles F.
1967. Process and significance of interception in Colorado subalpine forest. Int. Symp. Forest Hydrol. [Pa. State Univ., University Park] Proc. 1965: 213-224, illus.

Leaf, Charles F.
1966. Sediment yields from high mountain watersheds, central Colorado. U.S. Forest Serv. Res. Pap. RM-23, 15 p., illus. Rocky Mt. Forest and Range Exp. Sta., Fort Collins, Colo.

____
1967. Areal extent of snow cover in relation to streamflow in central Colorado. Int. Hydrol. Symp. [Fort Collins, Colo.] Proc. 1: 157-164, illus.

____
1969. Aerial photographs for operational streamflow forecasting in the Colorado Rockies. West. Snow Conf. [Salt Lake City, Utah] Proc. 37: 19-28, illus.

Martinelli, M. Jr.
1964. Watershed management in the Rocky Mountain alpine and subalpine zones. U.S. Forest Serv. Res. Note RM-36, 7 p., illus. Rocky Mt. Forest and Range Exp. Sta., Fort Collins, Colo.

Miller, D. H.
1953. Snow cover depletion and runoff. U.S. Army, Corps of Eng., N. Pac. Div., Snow Invest., Res. Note 16, 27 p., illus.

Parshall, R. L.
1941. Correlation of stream-flow and snow-cover in Colorado. Amer. Geophys. Union Trans. 22 (part 1): 153-159, illus.

Parsons, Walter J., and Castle, Glenn H.
1959. Aerial reconnaissance of mountain snow fields for maintaining up-to-date forecasts of snowmelt runoff during the melt period. West. Snow Conf. [Reno, Nev.] Proc. 27: 49-56, illus.

Potts, Harry L.
1944. A photographic snow-survey method of forecasting runoff. Amer. Geophys. Union Trans. 25 (part 1): 149-153, illus.

Retzer, J. L.
1962. Soil survey Fraser alpine area, Colorado. U.S. Dep. Agr., Forest Serv. and Soil Conserv. Serv. in coop. with Colo. Agr. Exp. Sta. Ser. 1956, No. 20, 47 p., illus.

Thoms, M. E.
1961. Summary of aerial snow cover observations in North Pacific Division, 1945-1960. U.S. Army, Corps of Eng., N. Pac. Div. Tech. Bull. 21, 9 p., illus. Portland, Oreg.

____
1969. Summary of areal snow cover observations in North Pacific Division, 1961-1968. U.S. Army, Corps of Eng., N. Pac. Div. Tech. Bull. 21 (Suppl.), 6 p. Portland, Oreg.

________ and Wang, H. P.
1969. Compilation and use of areal snow cover observations, Columbia River Basin, 7 p. Amer. Geophys. Union, Pac. Northwest Reg., Sixteenth Annu. meeting, Portland, Oreg.

United States Army.
1956. Snow hydrology. Summary report of the snow investigations. Corps of Eng. N. Pac. Div., 437 p., illus. Portland, Oreg.

Leaf, Charles R.
1971. Areal snow cover and disposition of snowmelt runoff in central Colorado. USDA Forest Serv. Res. Pap. RM-66, 19 p., illus. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado 80521.

Areal snow-cover depletion and resultant snowmelt and water yield were studied on three small watersheds in the Fraser Experimental Forest.

High water yield efficiencies were observed on two watersheds which had: (1) almost complete snow cover when seasonal snowmelt rates on all major aspects were maximum; (2) a delayed and short snow-cover depletion season; and (3) moderate recharge and evapotranspiration losses.

Water yield efficiency in one watershed with low-elevation south slopes was least. In 1969, streamflow from the drainage area on this basin below 9,850 feet was less than 30 percent of that generated from above this elevation. Fourteen years of comparative streamflow indicated that water yields from the low-elevation subdrainage can vary from near zero in poor runoff years to a maximum during good years of about 50 percent of the flow generated from the high-elevation subdrainage.

Key words: Aerial photography, runoff, snow surveys, stream gaging, hydrologic cycle.

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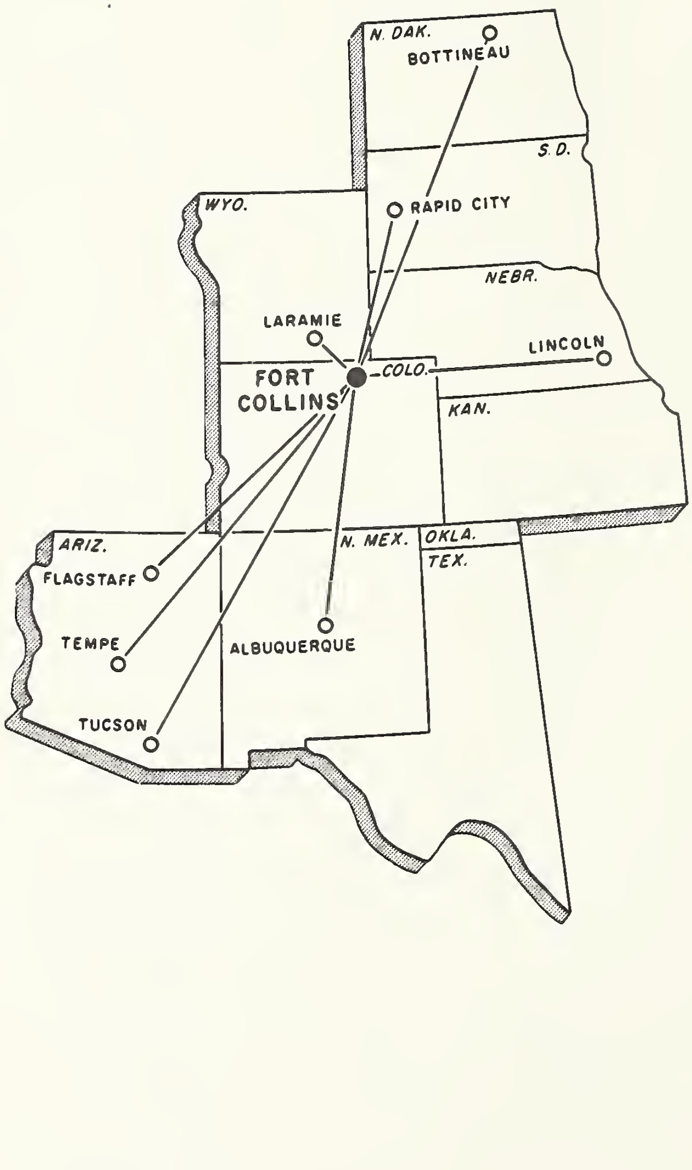
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